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Art XI.—*A 200 K.V. Neutron Generator.*

By L. H. MARTIN, R. D. HILL & J. DARBY.
(Physics Department, University of Melbourne.)

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Abstract.

A brief account is given of a 200 K.V. Neutron Generator, which can be readily constructed from materials available in an Australian laboratory. The ion source is a deuterium glow discharge of the Oliphant type. The equivalent activity of the generator is approximately 3 curies Rn – Be.

Introduction.

The simplest neutron source consists of a sealed tube containing beryllium powder mixed with radon. Historically this was the first type of neutron source used.

Although intense sources can be obtained by this method, they suffer from the defects of decay with a half-life of 3·8 days (the half life of Rn) and of an intense gamma-ray background from the radon decay products.

Artificial sources of neutrons have been developed using nuclear disintegrations in which neutrons are one of the products. These sources have the advantage of being constantly available, and beams of neutrons can be obtained with intensities far exceeding those available from natural radioactive sources.

The practicability of obtaining intense neutron sources from low voltage acceleration apparatus (as distinct from the cyclotron and the high voltage van de Graaff apparatus) was demonstrated by Oliphant and Rutherford.(1)

Neutrons were obtained from the D–D reaction, in which accelerated deuterons disintegrate deuterium to produce helium of mass 3, and neutrons,

i.e. $_1H^2 + _1H^2 = _2He^3 + _0n^1$

The efficiency of this reaction is comparatively high at low bombarding energies and the neutrons have approximately homogeneous energies in the region of 2·2 million electron volts.

The yield of neutrons in the above reaction is a function of the energy of the bombarding ions and their number. In high voltage generators such as the Van de Graaff machine, the ion current is quite small, usually of the order of 10 micro amperes. In low voltage generators, such as that described in this paper, the use of large ion currents offsets the low energy of the ions. To this end special attention has been directed to the design of the ion source, and several different sources have been described. Some of the more recent developments in neutron generator design are referred to in references (2), (3), (4), (5).

Acceleration Tube.

Originally it was intended that 200 K.V. should be applied across a single gap as in the Philips neutron generator; but it was found that continuous operation could not be attained above about 150 K.V. The failure to withstand the full potential was associated, we believe, with secondary electron emission, and attempts to limit this by the development of a well focussed ion beam and by its careful alignment were not completely successful. Accordingly, the accelerating tube was divided into two sections, each built to withstand 100 K.V., and reliable operation at the full potential resulted immediately. Stable functioning of the tube at full potential was

effected also by using very high resistances (c. 10 megohm) in the leads to the tube electrodes. The purpose of these resistances is no doubt to limit the growth of a discharge which might be initiated by a small burst of gas in the tube.

The potential of the target is determined partly by the purpose for which the generator is required. If the neutron detecting apparatus can be taken to a safe electrical distance from the generator, and if the source is of sufficient intensity, the target may be worked at high (negative) potentials. On the other hand, if the disintegration products are to be observed close to the target, or if the most intense source is required, it may be essential to earth the target.

In our generator we have favoured the simpler arrangement of an earthed source and high potential target. This has the constructional advantages that the power supply and liquid cooling for the source do not require high potential insulation or motor generators operating at high potentials. This arrangement also has the advantage that the accelerating tube can be built upwards towards the high potential electrode and in our generator the target was arranged to be at a convenient height for counter and cloud chamber experiments.

The construction of the accelerating tube may be seen from Fig. 1. The outer envelope is formed by two glass cylinders which are joined together by a steel ring R, the joint being made vacuum tight by Apiezon Q sealing compound. The ring R also holds the central electrode system and is connected to the 100 K.V. terminal of the high potential supply. The first gap E is basically a plane electrode system. This form, after extensive

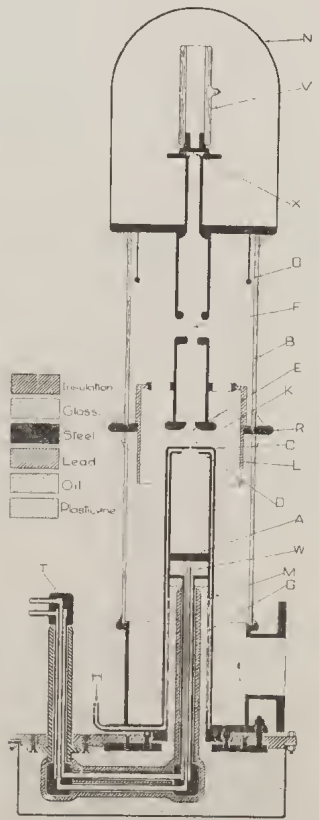

Fig. 1.—Neutron Generator.

tests, has proved the most satisfactory as far as stability against breakdown is concerned. It has been found that breakdown is due primarily to electrons which are dislodged at the upper electrode by the periphery of the ion beam. The electrode system shown in Fig. 1 with the slightly curved upper electrode has the property of directing these electrons back into the region of the canal K and thus prevents them producing ionization in the main body of the discharge tube.

It might be imagined that this electron emission could be reduced by increasing the aperture of the upper electrode in this gap. There is a limit, however, to the size of this aperture since the electrostatic field is strongly defocussing for positive ions in this region.

As a result of electrolytic tank experiments we tried cup-shaped lower electrodes in this gap. Although a cup electrode was designed with excellent focussing properties, it was inferior to the plane electrode system in regard to breakdown. The electric field, while satisfactory for focussing positive ions, allowed electrons from the upper electrode to escape into the tube.

A lead shield L about 3 mm. thick surrounds the first gap, and reduces to a tolerable dosage the 100 K.V. X-rays produced by electrons emitted at the upper electrode. This shield also protects the middle glass metal joint from direct bombardment by ions scattered from the ion beam. A similar shield O is provided for the upper glass metal joint. The middle shield also effectively limits the range of secondary electrons.

In the second acceleration gap F the upper electrode has an aperture of greater diameter than the lower electrode. The defocussing effect of this system is less serious than it would be in the first gap since the ions are already moving with a high speed.

The target X consists of a very thin layer of heavy paraffin wax melted on the underside of a ground copper plate. It is cooled by a mixture of dry ice in alcohol placed in a dewar vessel V on the upper side of the copper plate. The cooling mixture needs to be renewed about every half hour. The whole target assembly is enclosed in a rounded metal shield N.

The height of the target above the floor of the room is approximately 3 ft. 6 in. This is a most convenient height for manipulating specimens and counter equipment around the target and is particularly suited to experiments with the expansion chamber, where neutrons are required to traverse the chamber horizontally.

High Potential Supply.

The rectifying circuit for the 200 K.V. generator is shown in Fig. 2. Although the circuit is more complicated than is required merely to supply a potential of 200 K.V. it was chosen because it provides a mid-point of potential. The complication arises from the fact that the tank of the high tension transformer T_2 must be insulated from earth for 100 K.V. In the case of a two stage accelerating tube, such as that described above, the ion currents in each section are of different orders of magnitude, and it is preferable to supply each section directly from a separate condenser rather than from a potential divider.

The high potential supply was constructed from an old Greinacher $\pm$ 100 K.V. X-ray plant. In order to provide the transformer T_2 with the 100 K.V. insulation, a second transformer T_1 was used to excite it. Transformer T_1 was a discarded high tension transformer which was rewound with a 1/1 secondary winding and the insulation improved to withstand

100 K.V. The H.T. transformer T_2 was stood on 100 K.V. insulators and excited by the secondary of T_1. The filament transformer for the rectifier V_1 was also excited in the same way by a rebuilt 1/1 transformer insulated for 100 K.V.

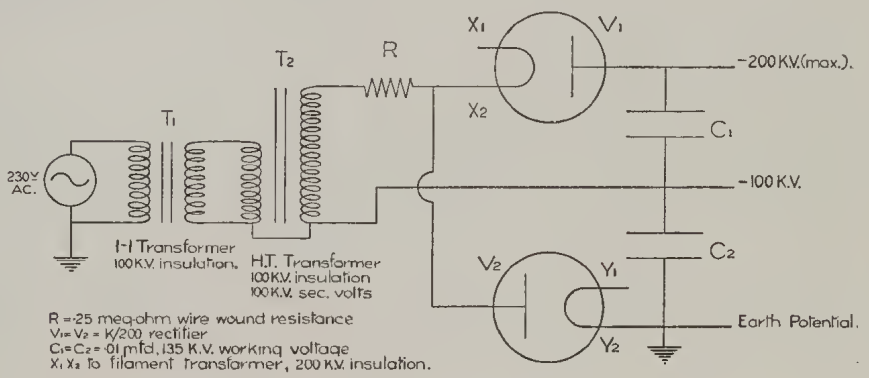

Fig. 2.—200 K.V. Supply Circuit.

A stabilizing water load was placed directly across the output terminals of the supply. The load was constructed from two coils of 3 mm. diameter (inner) glass tubing, each coil of about 25 feet length, and with ordinary tap water flowing continuously it had a resistance of about 200 megohm.

The ion currents flowing through the accelerating tube were measured by electrostatic voltmeters shunted with high resistances, since it was found that ordinary moving coil meters were too liable to damage when a sudden breakdown occurred in the tube.

All components of the high tension supply as well as the ion source supply were contained in a floor space of about 12 feet square and in a room 12 feet high. The distance allowed between high voltage components and from surrounding objects was approximately $1\frac{1}{2}$ inches per 10 K.V.

Ion Source.

Two types of ion source have been developed for use with neutron generators; namely, the glow discharge source and the low voltage arc source. The relative merits of these sources have been discussed by Craggs(2). Although it is likely that the low voltage arc source can provide an ion yield which exceeds that obtainable from the glow discharge source, there is little doubt that the latter is simpler to operate and maintain than the low voltage arc, and it was this feature that led us to employ the glow discharge source.

The construction of the ion source is shown in the main drawing of Fig. 1. It consists of two closed concentric cylinders A and C, the former being maintained at a positive potential between 20 and 35 K.V., and the latter at earth potential. The insulation of the anode A is provided by the glass cylinder G, which was constructed in the following manner. Two metal-to-glass seals were cut from a discarded Philips 200 K.V. Metalix X-ray tube, and the glass sections were then joined together in a glass lathe. The seals have proved to be mechanically robust, but must be protected from the gas discharge by a copper sleeve at M. The device of placing the insulation for the anode A within the cylinder C has conserved a considerable amount of length in the generator. Further length has also been conserved by providing the lead from terminal T to the anode A with oil and solid insulation. In this way 35 K.V. to the anode can be handled to within 2 or 3 inches from the base on which the generator is mounted.

In order that localized discharges will not build up between the walls of the cylinders A and C it is necessary to maintain the cylinders concentric with a separation of about 3 mm. The discharge is only strongly maintained between the anode block A and the cathode hole K. The diaphragm D, suggested by Craggs, has been used as an electrostatic lens to concentrate the discharge on the canal K. The anode runs hot under the intense electron bombardment from the discharge and solder seals are kept cool by a constant flow of water W behind the anode block. The supply of water comes from the mains through a coil of glass tubing to the inlet and outlet tubes on the terminal T. The water resistance has a value of about 60 megohms. The gas for the discharge is fed in through tube H and flows upwards between the concentric cylinders. Gas pressure in the discharge is approximately 0·1 mm. Hg.

Preparation of Deuterium.

Deuterium is prepared in the apparatus shown in Fig. 3 by the electrolysis of 99·6% heavy water. The volumes of the flasks and connecting tubes of the apparatus on the deuterium and oxygen side respectively are constructed as accurately as possible in the ratio 2 : 1. The electrolyte is prepared by dissolving 0·8 gm. of sodium peroxide in 20 cc. of heavy water and driving off all the oxygen liberated by gentle heating under reduced pressure. After evacuating the apparatus through either tap A or B, the electrolyte is introduced through the side tube C which is then sealed. In order to prevent excessive bubbling at the start when the gas pressure is low, the current should be limited to about 50 mA. At higher pressures, however, higher currents can be employed. A current of about 0·5 amp. is normally used and the heat which is generated is dissipated in a bath of ice water. Because of the 2 : 1 ratio mentioned above, the pressure on each side builds up at approximately the same rate, and when atmospheric pressure is reached the oxygen bubbles off through the mercury manometer, the deuterium being pumped off to the ion source through a needle valve D. The current can be adjusted so that for a particular consumption of deuterium the pressure in the generator remains constant. If the deuterium

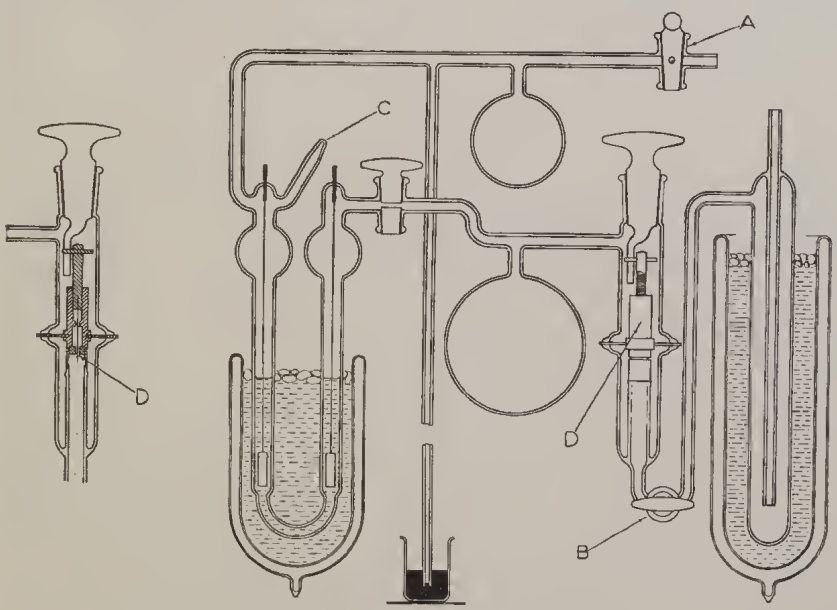

Fig. 3.—Deuterium Supply and Needle Valve.

is generated too quickly the electrolyte is pushed below the level of the cathode and electrolysis automatically stops. The volume of the flask and connecting tubes on the deuterium side is about 425 cc. and it takes three hours to fill this at atmospheric pressure.

Ion Source Characteristics.

Some typical characteristics of the ion source are shown in Table I, from which it appears that the ion yield increases with increasing potential on the discharge and is a maximum for an optimum gas pressure in the discharge tube.

Table I.—Discharge Tube Characteristics.

Discharge Potential (K.V.).	Discharge Current (m.A.).	Ion Current (μ.A.).	Pirani Reading Divisions.
16	6	50	0·8
20	11·5	100	(approx. ·1 mm. Hg.)
25	18·5	130	,,
30	21	160	,,
16	2	60	0·95
20	8	80	(slightly < ·1 mm. Hg.)
25	14	130	,,
30	20	170	,,
16	14	70	0·6
20	19	80	(slightly > ·1 mm. Hg.)
25	21	100	,,
30	24·5	120	,,

Some exploratory work has been done on finding the best size of the canal K. It has been found that the ion current issuing from the canal into the accelerating tube increases with increasing size of hole. For instance, the data of Table I. were obtained with a canal 1 mm. in diameter and 4 mm. long; whereas with a hole 1·5 mm. diameter and 6 mm. long the yield at 30 K.V. and the optimum pressure was 230μA. The geometrical divergence of the canal is the same in both cases. The maximum canal diameter is, of course, determined by the relationship of the pressures in the discharge and accelerating tubes to the speed of the pumping system. For example, with a canal 2 mm. wide and 3 mm. long it was very difficult to control the discharge pressure at the optimum value, and the pressure in the accelerating tube was also too great to withstand 200 K.V. continuously.

Up to the present we have had no opportunity of testing the effect of the size of the hole in the diaphragm D on the ion yield. The measurements above have been obtained with a 13 mm. diameter hole spaced 3 to 4 mm. from the cathode, as recommended by Craggs.

Pumping System.

As has already been mentioned, the ultimate yield of the generator is intimately connected with the size of the canal and therefore with the amount of gas which issues from the canal. Thus the pumping speed should be as large as possible. Further, in order that the full potential can be applied to the accelerating tube the mean free paths of ions and electrons in the gas of the tube must be long compared with the dimensions of the tube.

For a canal of 1mm. diameter and 4 mm. length the flow of hydrogen at a pressure of 10^{-1} mm. Hg. is approximately 90 litres per sec. The speed of pumping required at the first acceleration gap must therefore be of the order 100 litres per sec. at a pressure of from 10^{-4} to 10^{-5} mm. Hg. At these pressures the mean free path of a hydrogen molecule is from 1·3 to 13 metres.

We have used an oil diffusion pump having a speed of 300 to 500 litres per sec. at the pressures 10^{-4} to 10^{-5} mm. Hg. to exhaust the accelerating tube. Some trouble was experienced initially by having the pump too close to the accelerating tube as oil vapour entered the tube, and the ionized products of the oil led to gaseous breakdown. A length of water cooled wide diameter pipe with three right angle bends was then added to condense the oil before it entered the chamber. With this connection the pumping speed was somewhat reduced but it remained in excess of 100 litres per sec.

The oil diffusion pump was backed by a booster which could operate at a pressure of as high as 10^{-1} mm. Hg., and this in turn by a Megavac.

Neutron Yield.

Typical measurements of the generator characteristics are shown in Table II.

Table II.—Accelerating Tube Characteristics.

First Gap Current. (μA.)	Second Gap Current. (μA.)	Acceleration Potential. (K.V.)
800	400	160
800	430	180
750	500	200

It will be noticed that the ratio of the target current to the current in the first gap increases with potential, due no doubt to improved focussing as the speed of the particles increases. The current to the target is seventy per cent. of the ion current in the first gap, indicating that the focussing of the ion beam is very satisfactory.

The intensity appears to be comparable with that obtained by other workers. At 200 K.V. the yield per 100 micro amps. is approximately 600 millicuries.

Under best working conditions our neutron generator is equivalent to 3 curies of Rn – Be.

Acknowledgments

The construction of the neutron generator is preliminary to the study of the interaction of neutrons and the deuterium nucleus. This research is being carried out with funds made available by the Commonwealth Council for Scientific and Industrial Research.

The gas generator referred to under the section on Preparation of Deuterium was developed by Mr. D. Keam of this laboratory.

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